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Ka-Band PN Delta-DOR

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Workshop on Emerging Technologies for Autonomous Space Navigation
Hosted by Space Communications and Navigation (SCaN)/HEOMD
Thursday, February 16, 2017 9:30 a.m. – 6:00 p.m.
NASA HQ Auditorium (west lobby)

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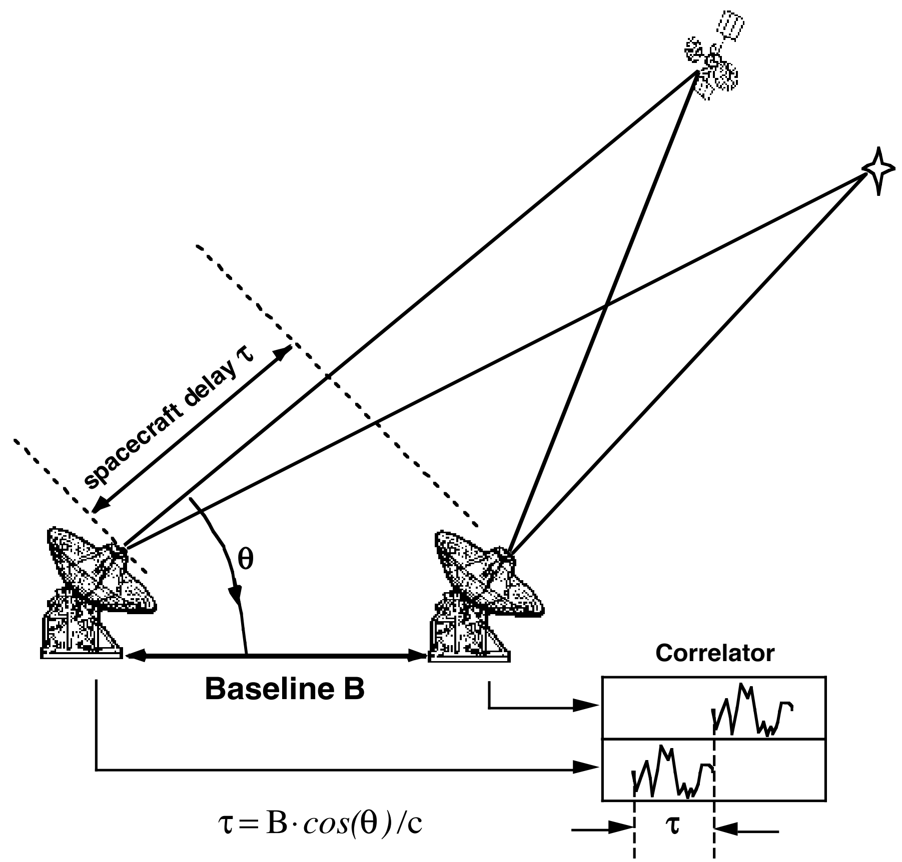
Delta Differential One-way Ranging

- **ΔDOR complements line-of-sight range and Doppler measurements**
- **ΔDOR uses interferometry to directly measure spacecraft angular position in the radio reference frame**
- **Accuracy has improved from 150 nrad in 1981 to 2 nrad today**
- **Many missions have used / will use ΔDOR**
- **Primary use is to improve targeting in plane-of-sky coordinates for encounters and other critical events**
  - **2 nrad is 300 m plane-of-sky position accuracy at Mars encounter distance**
- **Observations from 2 (long) baselines are needed to measure both components of angular position**



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Delta-DOR and Technology Development

- Delta-DOR has improved over the years by:
  - Identifying limiting error sources
  - Technology investments to reduce key errors
- Next chart shows improvements due to:
  - Spacecraft transponders with wider bandwidth DOR tones
  - Improved ground station open loop receivers
  - Higher bandwidth data recording
  - Better media calibrations
  - Better radio source catalog and reference frame
  - More sophisticated observing sequence
- This presentation: Where will the next improvements come from?

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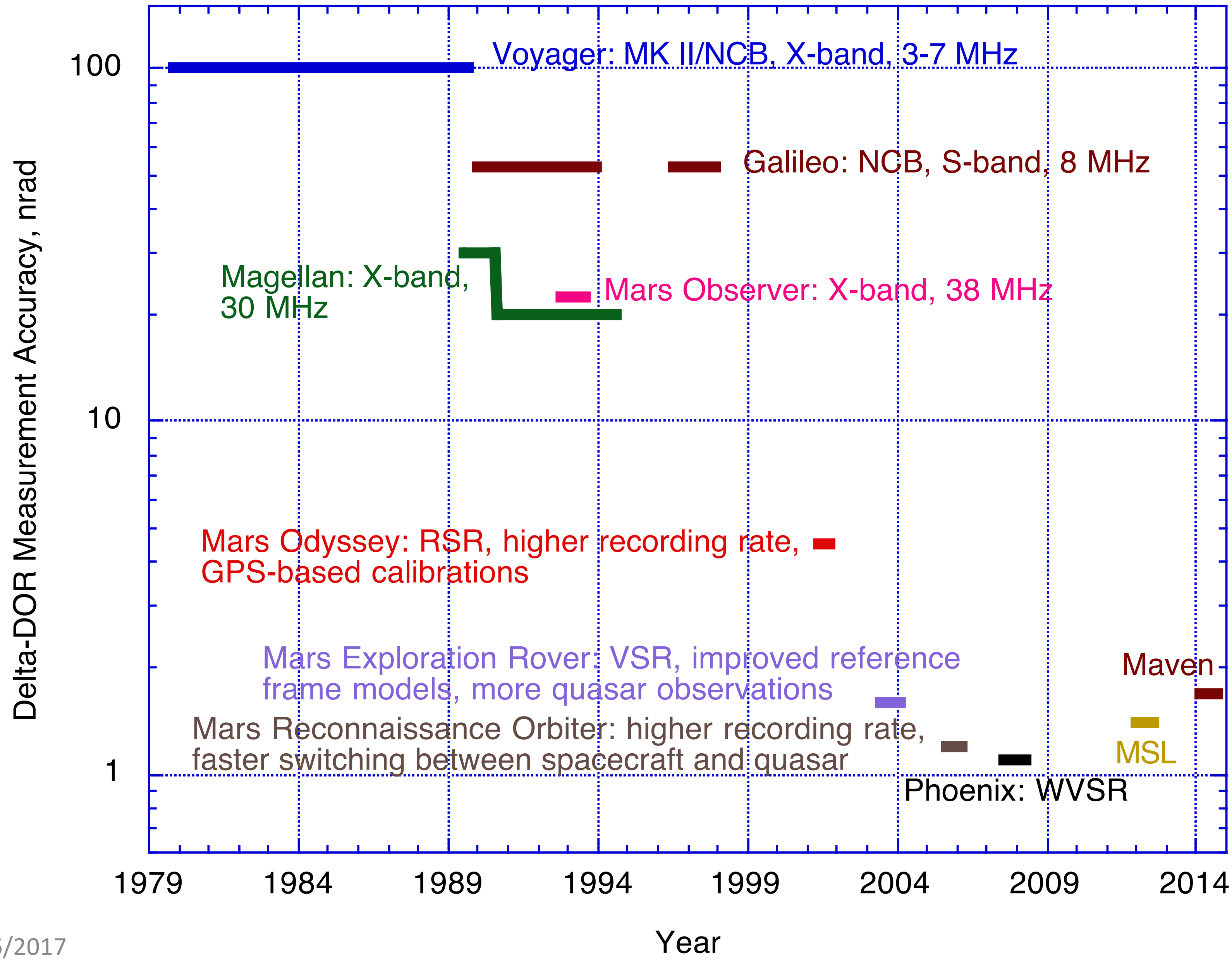
ΔDOR Accuracy Improvements



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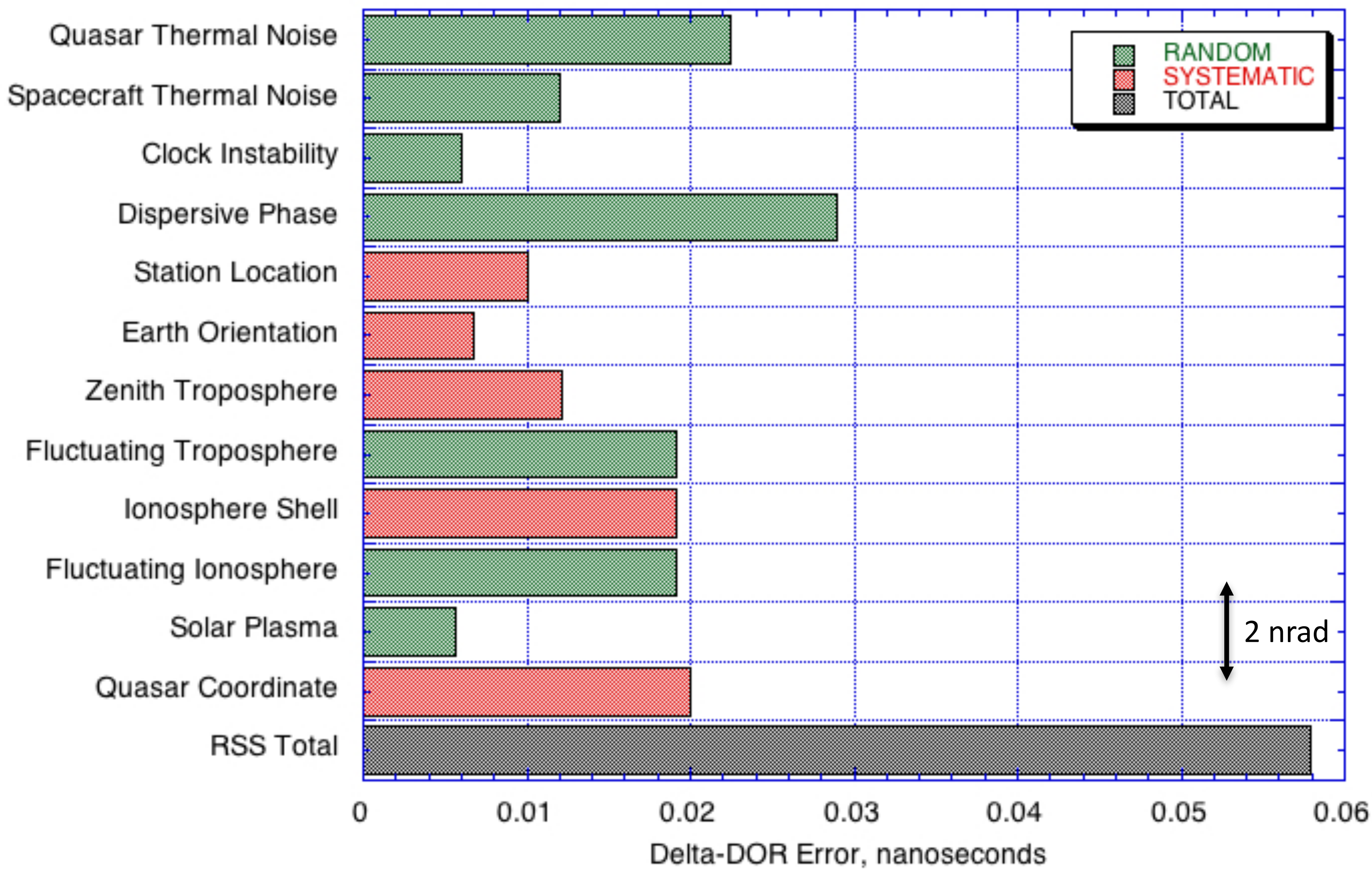
Current Delta-DOR Error Budget (X-Band)



Dispersive Phase: The Dominant Error

- Dispersive phase is the non-linear phase shift in ground station electronic components that is not common to the spacecraft and quasar signal
  - This component of the error budget has not changed very much
  - Today this error term stands in the way of a significant improvement in ΔDOR accuracy
- With the current spacecraft transponder design, DOR tones are generated by modulating a ~19 MHz sine wave onto the downlink carrier
- The quasar spectrum and the spacecraft spectrum are quite different – See next chart

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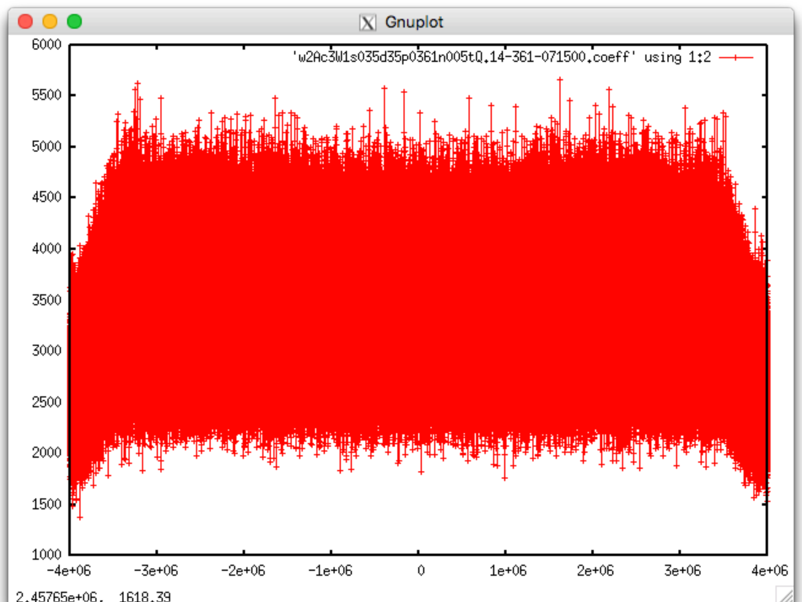
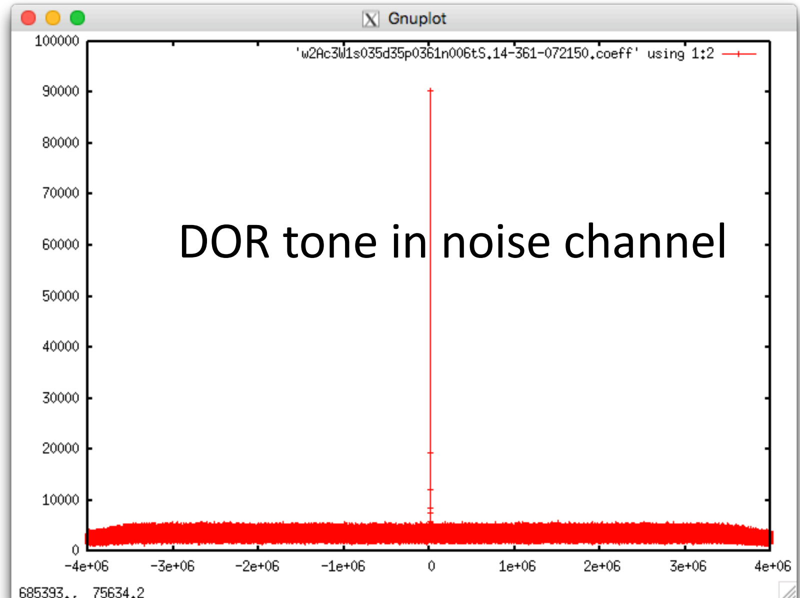
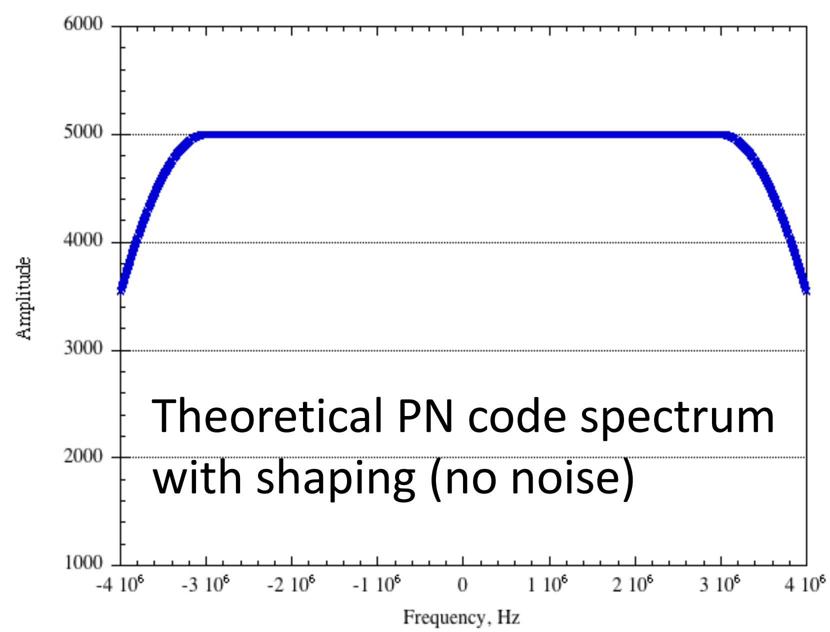
Comparison of Signal Spectra in 8 MHz Channel of Open Loop Receiver



Quasar signal buried in noise channel





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Proposed Pseudo Noise (PN) DOR Signals

- The sinusoidal DOR tone is multiplied by a PN sequence before modulating the downlink carrier
  - A suitable PN sequence could be generated with a linear feedback shift register (LFSR)
    - A gold code or other codes used for CDMA applications could be used
  - The chip rate is chosen to fill the bandwidth of interest
    - 4 Mchip/s could be used to fill an 8 MHz baseband channel
  - The DOR signal could be shaped by a filter such as a square-root raised cosine filter to flatten the spectrum
  - A long code sequence could be chosen to help resolve the ambiguity within a single channel
- A PN signal filling a frequency channel would more closely resemble quasar white noise
  - This will provide for near cancellation of the phase dispersion error between spacecraft and quasar recordings
- Implementation of the PN DOR signal should be straight forward in digital transponders
- Use of spread spectrum for the DOR signal will lessen the possibility of radio interference between the DOR signal of one spacecraft and the carrier signal of another spacecraft

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Ka-Band Downlinks

- Spacecraft transmitted bandwidth can be increased to take advantage of wider spectrum allocation for space research
  - Allocation is 50 MHz at X-band and 500 MHz at Ka-Band
- Quasar coordinate error is reduced since radio sources tend to have smaller cores and less structure at higher frequencies
  - Continued radio source catalog development is necessary
- Charged particle errors are reduced by a factor of 15 relative to X-Band

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Further Accuracy Improvements - 1

- With PN DOR
  - Dispersive phase is significantly reduced
  - Channel bandwidth can be increased without making dispersive phase worse
  - Increased channel bandwidth reduces error due to quasar thermal noise

- With Ka-Band
  - Spacecraft transmitted bandwidth can be increased to take advantage of wider spectrum allocation for space research
  - Quasar coordinate error is reduced since sources tend to have smaller cores and less structure at higher frequencies
  - Charged particle errors are reduced by a factor of 15 relative to X-Band
  - Better troposphere calibration is technically possible
    - When troposphere stands as the dominant error, and if better ΔDOR accuracy is required, then there will be ways to address this issue

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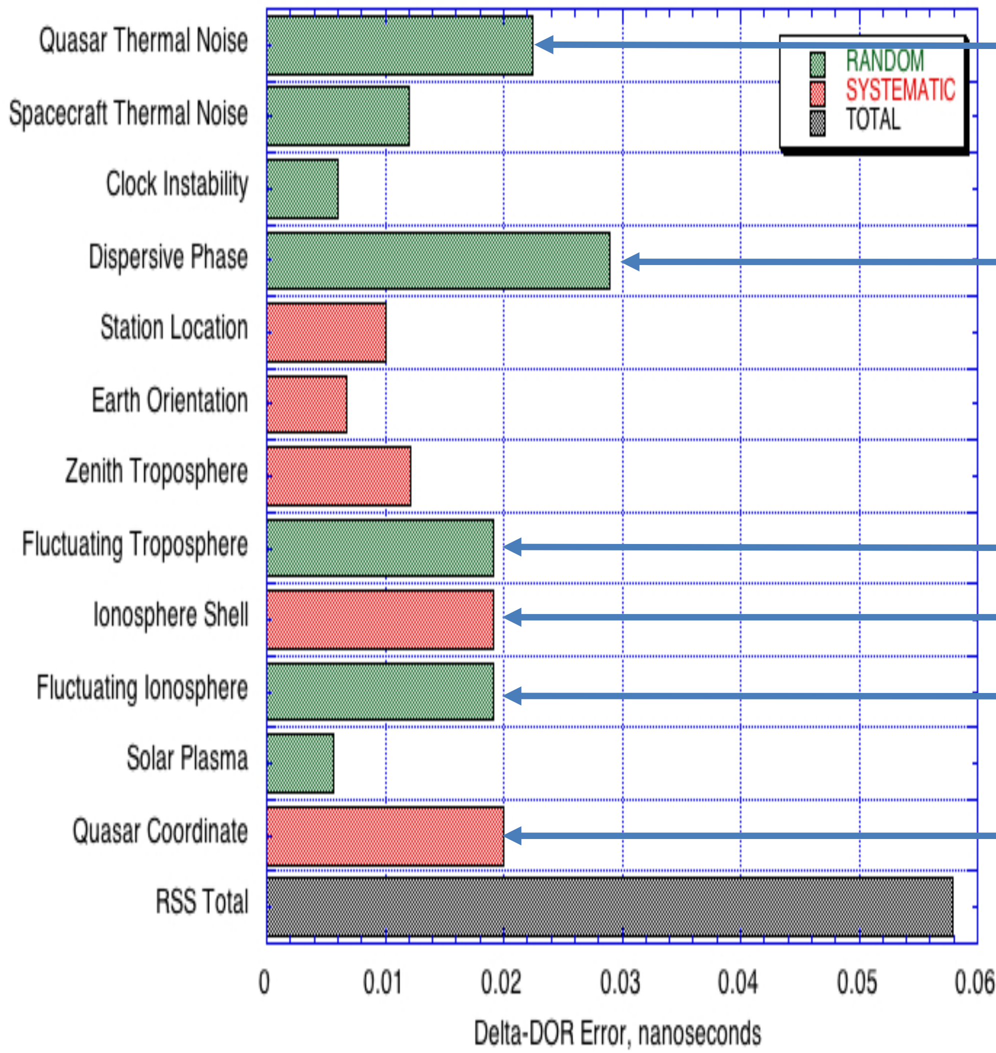
Further Accuracy Improvements - 2

Existing Error Budget



Technique to Improve Accuracy

- Quasar Thermal Noise: Reduced by PN and Ka-Band
- Dispersive Phase: Reduced by PN
- Fluctuating Troposphere: ???
- Ionosphere Shell: Reduced by Ka-Band
- Fluctuating Ionosphere: Reduced by Ka-Band
- Quasar Coordinate: Reduced by Ka-Band

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Conclusions

- PN DOR is necessary to reduce what is now the dominant ΔDOR measurement error
- It should be straight forward to implement PN DOR in digital transponders
- Ka-Band allows additional improvements to all remaining large error components, except for troposphere
- When troposphere stands alone as the dominant error, and if better ΔDOR accuracy is required, then there will be ways to address this issue